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A PROGRAM FOR WATERSHED MANAGEMENT RESEARCH IN HAWAII WILDLANDS

Henry W. Anderson, Walt Hopkins, & Robert E. Nelson

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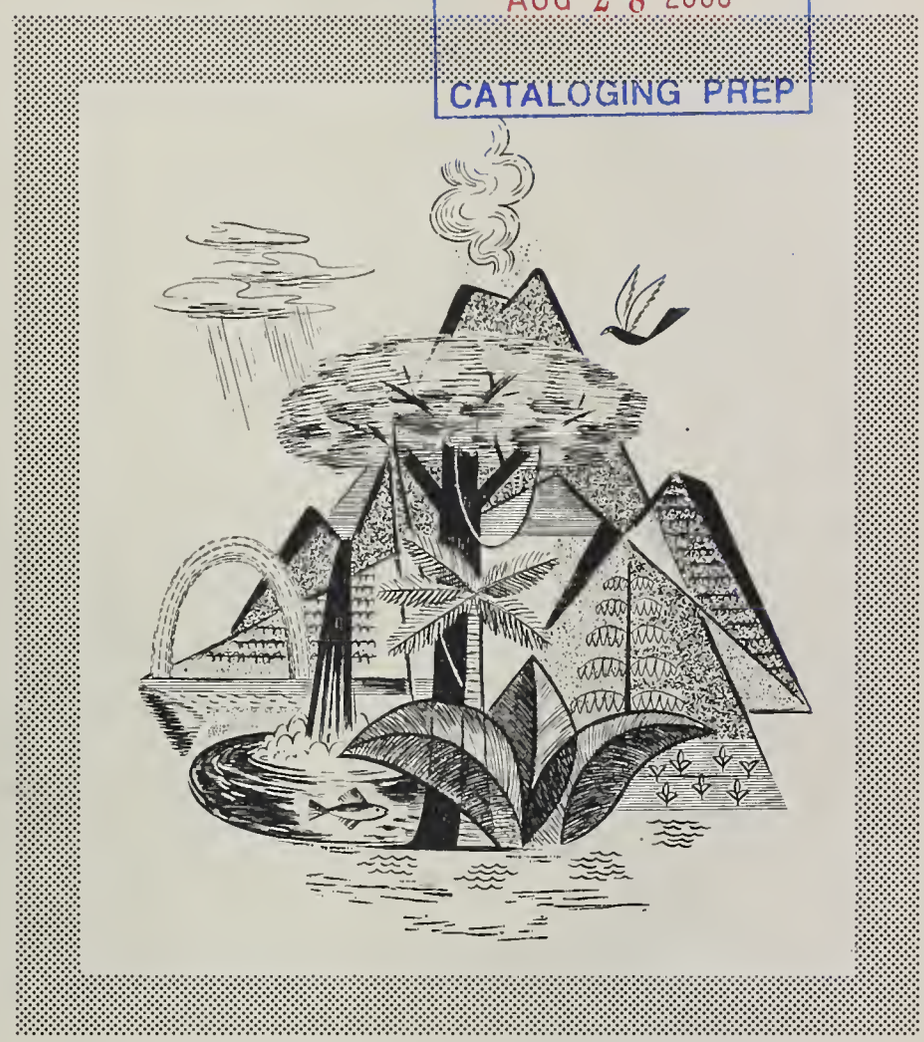

Pacific Southwest Forest & Range
Experiment Station - Berkeley, California
Forest Service - U.S. Department of Agriculture
in cooperation with
Forestry Division, Department of Land & Natural Resources, State of Hawaii

1962
Technical Paper 72

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By

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U.S. DEPARTMENT OF AGRICULTURE, FOREST SERVICE

PACIFIC SOUTHWEST FOREST AND RANGE EXPERIMENT STATION

Berkeley, California

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Water is the only crop from many of Hawaii's mountain watersheds, and its importance has long been recognized. Probably nowhere in the United States has a more intensive and successful program of watershed protection been developed than in Hawaii. Can these wildland watersheds be managed to produce even greater quantities of water to meet the expanding needs of the fiftieth State?

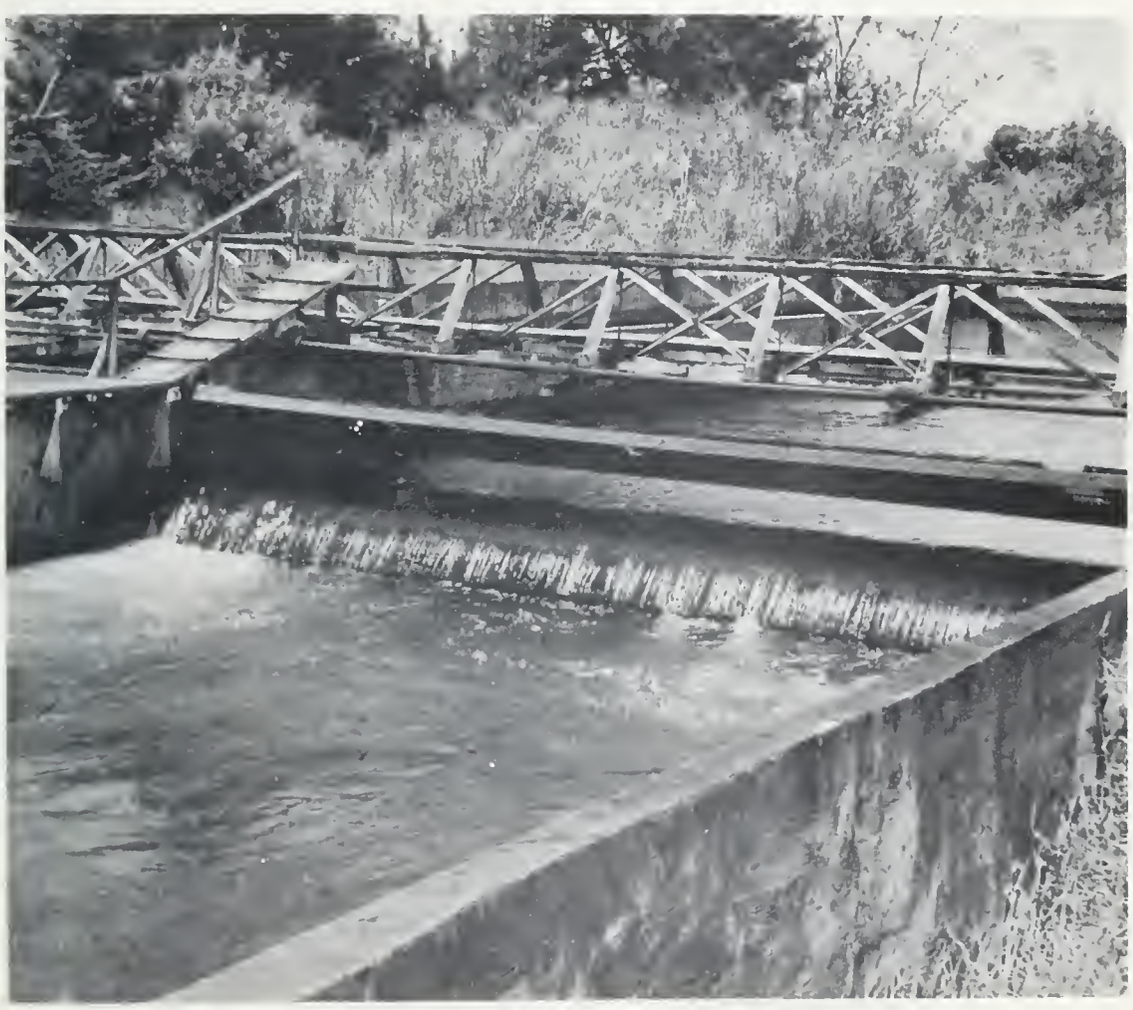

Figure 1.--Water is the only crop from many of Hawaii's mountain watersheds--east Maui irrigation weir.

As the need for water grows, pressure continues to mount for other uses of this land--to provide homesites and industrial areas, to produce timber and forage, and to support outdoor recreation. If these uses are to be expanded with only minimum jeopardy to water supply, Hawaii's land managers must know more than is now known about Hawaii's watershed conditions and the ways land use affects the water crop.

As a guide to effective management, we need specific information on watersheds, their soil, vegetation, and topographic characteristics, and their variability in receiving and discharging water in different climates. Information is particularly needed on the effects of land use and of changes in land use upon the amount and quality of water yield, infiltration of water into the soil, surface runoff, floods, and sedimentation.

Answers can be obtained through a four-step research program: (a) statewide inventories of present watershed conditions in Hawaii, (b) a series of basic forest hydrology and meteorology studies, (c) plot and small-scale tests of alternative management practices, and (d) pilot testing of selected methods on calibrated watersheds. Knowledge gained from this research will point out methods of managing and protecting Hawaii's wildland watersheds that will:

- Assure the continued flow of high quality water from mountain watersheds.

- Maintain or improve water quality.

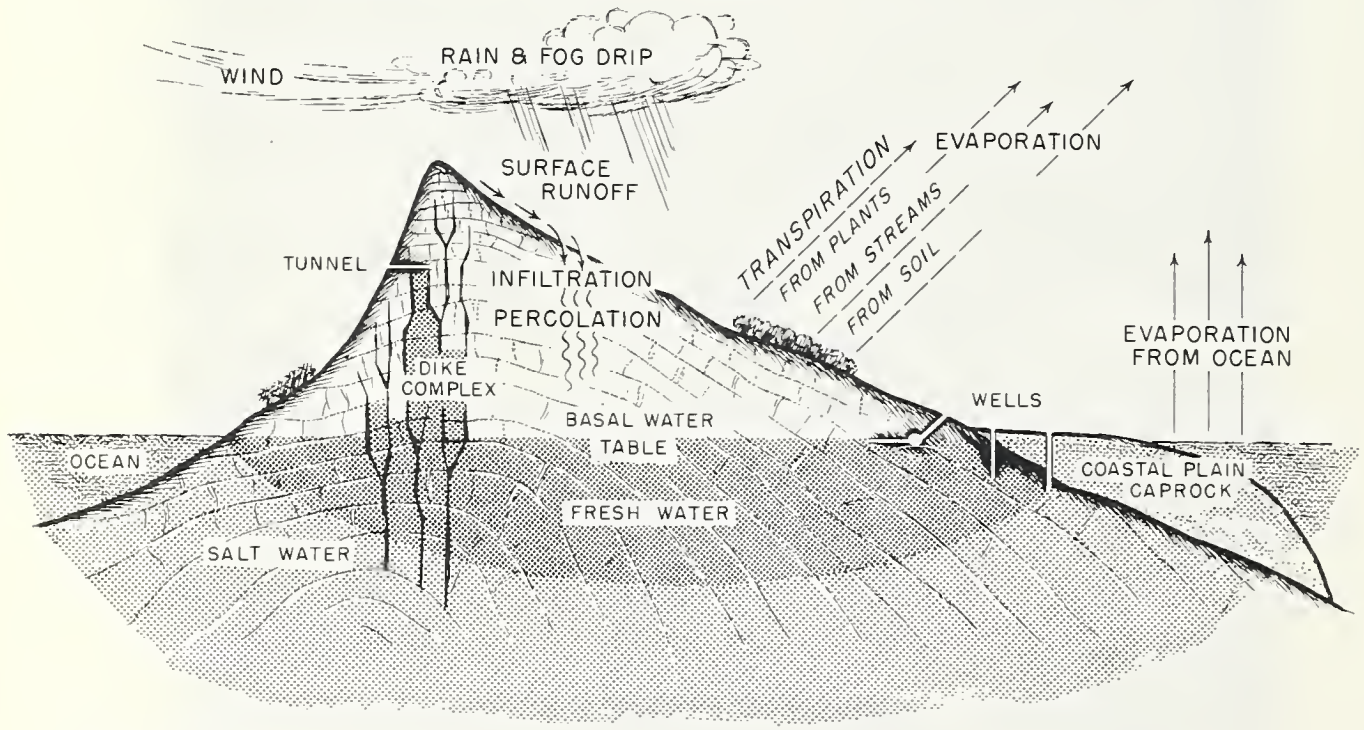

Figure 2.--The hydrologic cycle runs it course. Rain and fog drip into the soil and rock or run off the surface. Evaporation and transpiration return moisture to the air.

- Improve the distribution of water yield by modifying the balance between ground recharge and surface water flows.

- Regulate or improve the timing of water yield, particularly in dry seasons or dry years.

- Increase water yield by decreasing evaporation and transpiration losses.

- Minimize flood runoff and reduce sedimentation.

INVENTORIES OF PRESENT CONDITIONS

Watershed characteristics differ greatly from place to place. To determine the broad situations that require research, a series of inventories of vegetation, water yield, soil characteristics, and physiographic and climatic sites should be launched. These surveys would outline the land areas subject to each management practice. They would point up areas where treatment would be the most effective for water yield and where treatment for water and sediment control would be most needed.

Some inventories can be made by compiling data from such existing sources as maps, aerial photographs, reports, and other published material. Other inventories will require on-the-ground surveys and sampling of the main topographic, geologic, soil, and vegetation types. Inventories may need revision after research points out significant physical differences, identifies special problems, and indicates possibilities of management.

VEGETATION AND LAND TYPES

An inventory of forest and other land types should tell us their locations, conditions, and extent. It should determine the areas of brush, grass, ohia-fern jungle, stream-bottom growth, bare ground, and rock. It should also describe the related topographic, climatic, and geographic features. Various authorities have gathered data on the geography of Hawaii, but this information is too general for watershed management research. Ripperton and Hosaka (1942) have made broad delineations of the vegetation zones in Hawaii. These zones were described largely by total annual rainfall and by elevations. Foster (1939) has delineated broad land-use zones within the wildlands.

Probably the most useful information to watershed management--both research and application--would be derived from maps of forest and other land types superimposed on maps of geomorphic provinces described by Wentworth (1939). An inventory should be made of species types, densities, sizes of openings, and riparian types, by geomorphic provinces and by elevation zones. Wentworth's geomorphic provinces should be refined and modified as necessary on the basis of new information of such physical changes as recent lava flows.

WATER YIELD

Streamflow from mountain watersheds accounts for 60 percent of all water used in Hawaii (Hawaii Water Authority 1959). To improve or maintain water yield, we must know the amounts, timing, and variability of streamflow yields.

Streamflow and ditch flow have been measured at more than 465 points in Hawaii. Records available vary in length from a few months to as much as 40 years. These should be analyzed to locate and evaluate the principal water sources and to establish the relation of streamflow to climate, topography, geology, and vegetation variables. These analyses will determine the amount of streamflow from each physiographic province and the time when water is yielded.

FLOOD FLOW

Floods originating in mountain watersheds in Hawaii are frequent. The potential damage from floods is high because of the combination of intensive tropical rainstorms, short precipitous stream channels, and narrow coastal plains occupied by cities and other improvements. The principal flood sources can be located and evaluated by analyzing available records.

Figure 3.--Damaging floods often develop in Hawaii's watersheds. Fundamental knowledge is needed of the relationship of floods to storm characteristics, topography, geology, and vegetation. (Photo by U.S. Soil Conservation Service.)

The relationship of floods to storm characteristics, topography, geology, and vegetation should be analyzed. Such an analysis will guide both the research and application of vegetation management for flood prevention by pointing out the major flood sources.

CLOUD CHARACTERISTICS

Clouds affect water supply and may be "managed" to yield more water (Hawaii Water Authority 1959). Land managers on the island of Lanai, for example, have added 50 inches of "fog drip precipitation" to a mountaintop area by planting Norfolk-Island-pine on a cloud-swept ridge. If we are to manage vegetation for greater fog drip, we must know more than we do now about cloud characteristics. The further possibility of seeding warm clouds to induce rainfall justifies cloud research.

Clouds may modify evaporative losses from land and vegetation surfaces by their role in the interception and reflection of solar radiation and in re-radiation. Cloud characteristics and frequencies must be known in designing studies aimed at developing methods of reducing evaporation and transpiration through vegetation management.

Available information should be assembled and additional data collected as needed to permit delineation of cloud frequencies and characteristics, by physiographic and climatic provinces of the State.

WIND VELOCITIES AND FREQUENCIES

Trade winds, Kona winds, and land and sea breezes play an important part in nearly all aspects of the State's water supply. Trade winds and land and sea breezes affect rainfall, fog drip, evaporation, and transpiration.

We must know wind velocities and frequencies at various sites if we are to properly assess the potential of wind erosion and evapotranspiration and devise vegetation control measures. The general relationships of trade and Kona winds to precipitation are well known. But we need more information on the relation of topographic barriers and elevations to winds.

A wind inventory should be made for the major physiographic provinces and elevation zones within the provinces. Available data should be collected and surface winds sampled as needed so that frequencies of wind velocities and directions can be related to topographic conditions.

RAINFALL

Rainfall has been measured at more than 440 sites in Hawaii. Generalized mean annual precipitation maps have been drawn from these data. But more information is needed on the way rainfall varies with local topography. We could add greatly to what we know about these variations by making some rather simple analyses of presently available rainfall

data. Such analyses have been successful for areas having fewer rain measurements and less variation in rainfall (Spreen 1947; Burns 1953).

Available rainfall data should be used to relate rainfall of trade, Kona, and orographic storms to various topographic variables. To correct any gaps in sampling, the adequacy of the present rainfall station network should be evaluated.

SOIL CHARACTERISTICS

Soil characteristics, as much as any other factor, determine how land may be managed in watersheds to improve water yield or control water. For the most effective management, we must know the infiltration capacity of surface soils, the permeability of underlying horizons of each major soil type, and the extent and location of soils having different water-holding capacities. We must know the physical and chemical characteristics of soils associated with various geologic types and climatic conditions and how these characteristics vary from place to place. We need first approximations of water loss through transpiration and evaporation from soils on various aspects and slopes and for soils of various depths.

Figure 4.--Gullies indicate loss of soil and productivity. Erodibility indexes of different soils can provide a basis for determining land management practices.

Standard soil surveys have been completed for much of Hawaii. Wildland soils need to be classified and mapped according to series and phases. An inventory should be made of the major geologic soil types. Soil characteristics should be related to geologic parent material, rainfall amounts, topography, and vegetative cover. Soil types should be characterized as to infiltration capacity, permeability, moisture storage capacity, and erodibility. Erodibility indexes can be developed from physical measurements of soils as determined under varying geologic, vegetation, and climatic conditions (Anderson 1954).

EVAPORATION POTENTIAL

The evaporative potential at a forest site, other things being equal, will determine the type of management or limit possibilities for water yield increases by management of the vegetation. This potential can be estimated by using rainfall, cloud, and wind inventory data and known information on the solar radiation received by various slopes in the absence of clouds (Chang 1961; Ekern 1962).

These estimated potentials should be checked against measured losses from soil, or by using atmometers placed in the field, or by comparison with evaporation measured in standard evaporation pans. Then zones of evaporative potential should be delineated on various sites.

BASIC FOREST STUDIES

FOREST HYDROLOGY

To understand what goes on in watersheds we need basic studies on forest hydrology, forest meteorology, and plant-soil-water relations. Forest hydrology concerns methods of measuring and interpreting basic hydrologic processes in the search for answers to such questions as: What happens to rainfall and atmospheric moisture? How is water yield divided into streamflow and ground water? What are the effects of rainfall and streamflow on erosion and sedimentation? What happens to precipitation after it has fallen and to drifting fog after it has been "intercepted"?

Can evapotranspiration be related to soil moisture losses during the dry spells that often occur in June, September, and October, and can these be related to atmoshperic moisture and solar radiation or to evaporation pan data so that we may predict losses in other periods?

In studying fog drip, we face these problems: What is the net gain of water by fog drip along the coast, on mountain slopes, and on exposed ridges? How is the amount of gain related to tree species, tree spacing, and location on the slope?

Forest hydrology studies will reveal how and when water is yielded under various forest sites and under various soil and geologic conditions. How much water runs over the surface? How much percolates into the soil and comes out as quick seepage or goes into ground water storage? We should find out by what processes and how frequently rainfall contributes

Figure 5.--What happens to moisture in the clouds when it reaches the watershed?

Figure 6.--Fog drip glistens on tree leaves. Research is needed to determine the net gain of water by fog drip and its relationship to tree species, tree spacing, and location.

to streamflow and floods and how forest conditions affect these contributions. We need to investigate the contributions of debris, organic matter, and sedimentation to the bulking of flood flows. We should study the effects of forest fires, roads, logging, grazing, and vegetation conversion on the hydrologic processes.

Studies of sedimentation processes will lead to methods of minimizing erosion, controlling sediment transport, and reducing sediment deposition. We need to study how much and what ground cover is needed to give various levels of protection to different soils under prevailing rainfall intensities and wind conditions. We should also investigate the relation of steepness of slope and length of overland flows to vegetation and management measures needed to prevent gullying.

Other problems that merit research include these: How can windflow be interrupted to prevent blowouts or control them once they have started? Why do raw spots at the edge of canyons and on some slopes fail to heal? What controls are required in road design, drainage, and maintenance to minimize erosion? Why are some soils almost indestructible?

Figure 7.--Crumbling soil washes down into a stream channel. Studies of the physical processes in the origin of erosion and floods would help determine the steps needed in their control.

Sediment transport in channels depends on the size of particles, the slope of the channels, and the extent of the runoff potentials. These inter-relationships may imply such management possibilities as channel barriers, low sills, vegetation, and others that bear investigation. Is management for sediment control most effective by controlling surface erosion or channel scour, by affecting deposition, or by influencing the total sediment transport?

FOREST METEOROLOGY

We must know the meso-, macro-, and micro-meteorological conditions of forest sites to understand hydrologic processes. The relationship of precipitation to topographic exposure and to the trade and Kona storm paths must be known. Similarly, wind characteristics in relation to trade versus Kona winds and to elevation and topography must be understood. Heat budget at forest sites must be determined. We should know what happens to solar radiation: the amounts reflected, absorbed in forest stands, and lost by long-wave radiation. A study of forest meteorology should also cover advective heating and turbulent exchange as affected by winds, clouds, and topography at forest sites. From such studies, measurable variables may be found that will index meteorological influences on water yield and water control.

PLANT-SOIL-WATER RELATIONS

This group of basic studies explores two types of relationships: (a) the ecological relationship of plants to their environment, and (b) the relationship of plants to soil properties, including soil moisture.

Ecological relations particularly important to water conservation are the degree of tolerance and response of plants to conditions in which we may want them to grow. Of importance is the tolerances of various species to different types of soils--shallow, fine-textured, coarse-textured, alkaline, acid--to dry or saturated sites, and to windy sites. We also want to know their tolerance or response to grazing and burning, and to competition from like and unlike plants. What is the tolerance of plants to such applied treatments as defoliation to save water in dry years, or diversion of streams above riparian areas?

Soil relations may have a decisive role in watershed management. Species having strong tap roots may break up soils with impermeable iron-pans. Some hydrol-humic soils react drastically to drying; the soil aggregates lose their clayey properties and become sand-like. Erosion and exposure of soils to drying may modify their water-holding capacities. Some soils are excessively drained. They may be difficult to handle when we try to convert the existing scrub ohia to better timber species. Fostering the growth of desirable species may require an exact knowledge of rainfall and fog drip conditions. Some soil conditions may be identified by so-called indicator species of vegetation, which will be a clue to how those areas may be managed for water yield, erosion control, or timber.

An example of how a species is adapted to ecological and edaphic requirements of a site is a stand of Norfolk-Island-pine growing on the island of Lanai. An objective in watershed management there on a high cloud-shrouded ridge is to induce fog drip. The species appears to be an efficient interceptor of fog. It seems to grow well in saturated soil conditions which fog interception brings about. It tolerates the shallow soil (about 1-foot deep) underlain by an ironpan. The species develops rapidly on these sites after it reaches the height of surrounding shrubs and starts intercepting fog. A simple mechanical fog interceptor placed near each pine at the time of planting might speed early growth.

PLOT AND SMALL-SCALE TESTS

Results of basic forest studies will point up promising practices of watershed management. These approaches can then be tested in plot and small-scale experiments. Some simple measurements can give clues to the relative effectiveness of each practice. What happens to precipitation? What happens to soil? What are the consequences in terms of floods and erosion?

In plot and small-scale trials, artificial devices can be tested and compared with vegetation, as for example, in trapping fog. We can measure the effects of logging and other soil disturbances and evaluate the effects of vegetation type conversion. By determining the effects of each practice on soil moisture loss, infiltration, interception, and evapotranspiration, perhaps we can estimate the effects on streamflow and water yield.

Plot experiments should also be the first step in testing hypotheses of "model" forests for water conservation or for flood and sedimentation control. Forest patterns aimed at these objectives have been developed through fundamental watershed research. Undoubtedly similar hypotheses will be devised for Hawaii's forests, and should first be tested on a small scale. These small-scale trials can be expected to indicate the most promising methods for follow-up pilot-plant tests on parts of large watersheds or on whole small watersheds.

PILOT TESTING OF SELECTED METHODS

Pilot testing of selected watershed management alternatives will usually be necessary because we cannot always safely multiply small-scale test results to predict results with accuracy on large watersheds. The size factor strongly affects floods, sedimentation, and--to some degree--ground water yields. The end products of large-scale experiments should be measured in such terms as streamflow, ground water yield, and sedimentation. The pilot watersheds must be calibrated in advance so that we can evaluate the statistical significance of the effects of management and can assign a probable error to the results.

Figure 8.--A radioactive probe measures the amount of moisture in the soil.

Existing gaged streams in Hawaii should be carefully examined to find suitable and available experimental watersheds. At least 300 active and inactive gaging stations might be considered for these tests. The U.S. Geological Survey has operated most of these stations, and records are available. Other gaged streams have been managed by private companies, and records may be available upon request. The suitability of gaged streams and the availability of records for research should be explored in cooperation with other agencies, including the U. S. Geological Survey and the Hawaii Department of Land and Natural Resources. Several pairs or

groups of watersheds should be set aside for experimental purposes at an early date.

The final selection of watersheds would be guided by the results of inventories of forest types, climatic and physiographic provinces, and soils. The watersheds chosen for experiments would then be intensely surveyed. The necessary steps include making detailed maps and characterizations of soils, substratum geology, forest or other vegetation types, topography, precipitation, and climate. Streamflow records of the selected watersheds would be analyzed and correlations made of streamflow between watersheds and with meteorological records. The predictability of the streamflows would be evaluated. We could then make quantitative and statistical evaluations of the effects of management, such as vegetation type changes, on streamflow and sedimentation.

PROPOSED RESEARCH STUDIES

It is not our intent to specify who should make the inventories or conduct basic studies proposed in this report, nor to indicate when such research should be carried out. As a minimum the available inventory data should be gathered and analyzed sufficiently to show the range of problems and conditions requiring investigation. Inventories are needed as a first step in designing and executing basic research.

Basic studies can be carried out in the field, in laboratories, or for that matter in a person's head. They can be keyed to opportunity. They are best carried on where the researcher has frequent contacts with other scientists and has ready access to educational institutions, government agencies, and private industry.

Following is a list of specific inventories, basic studies, plot and small-scale tests, and pilot trials proposed for Hawaii's wildland watersheds:

I. Inventories

1. Vegetation type and conditions, by geomorphic and climatic provinces.
2. Water yield, by geomorphic and climatic provinces as related to vegetation types.
3. Flood sources, by geomorphic provinces, and their relation to climate and vegetation.
4. Cloud characteristics, by geomorphic provinces, elevational groups, and seasons.
5. Wind characteristics, by geomorphic provinces as modified by local topography.
6. Rainfall amounts and frequencies, by elevations in geomorphic provinces.
7. Soil infiltration and storage capacities and soil erodibility, by major soil-geologic types.
8. Evaporation potential, by geomorphic and climatic provinces and elevation.

II. Forest Hydrology and Sedimentation Studies

9. Interception of Kona-type rains, by vegetation as related to precipitation in the open.
10. Net precipitation during storms on wet-side sites related to open precipitation and climatic conditions.
11. Fog drip in nonstorm periods as related to topographic site, forest conditions, and climate.
12. Infiltration and depression storages as related to soil and forest conditions.
13. Evapotranspiration as measured by soil moisture and rainfall losses in inter-storm periods at forest sites.
14. Evapotranspiration during storm periods.
15. Monthly and peak discharges as related to rainfall, topography, soil, climate, and vegetation.
16. Ground water tables as related to rainfall, topography, geology, climate (time of year), and vegetation.
17. Water erosion as related to vegetation cover, soil erodibility, length of overland flow, and rainfall characteristics.
18. Wind erosion as related to wind velocity, surface soil protection, and barrier heights and locations.
19. Sediment transport in channels as related to channel slope, sediment sizes, and streamflow characteristics.
20. Reservoir and channel deposition as related to "trapped efficiency" and sediment sizes.

III. Forest Meteorology Studies

21. Precipitation characteristics of trade versus Kona rains, such as intensities, amounts, and drop sizes.
22. Precipitation amounts as related to topography and exposure to trade winds and land and sea breezes.
23. Wind velocities and direction as related to topography, vegetation, and exposure to trade winds and land and sea breezes.
24. Cloud characteristics as related to topography, vegetation, and exposure to trade winds and sea and land breezes.
25. Monthly heat budgets as related to topography, clouds, vegetation, and exposure to trade winds and land and sea breezes.

IV. Plant-Soil-Water Relations Studies

26. Tolerances and responses of vegetation species to such site and management conditions as soil depth, acidity, moisture, and competition.
27. Tolerances of principal timber and watershed management species to problem sites and to various treatments.

V. Plot and Small Scale Tests

28. Study of "fog drip" species.
29. Study of ironpan penetrating species.
30. Study of surface runoff problem species, including bamboo, staghorn fern, haole Koa, and Kukuia grass.

VI. Pilot Testing of Watershed Management Methods

31. Study of the suitability of presently gaged watersheds for pilot watershed tests.

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